The Effect of Hair and Football Helmet Fit on Headform Kinematics

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I. INTRODUCTION

The fit of football helmets varies widely [1] and football players have varying amounts of hair, ranging from bald to long dreadlocks. One previous study quantified head-helmet interface pressure and investigated the effect of helmet fit on headform kinematics at various impact locations at ~9.3 m/s [1]. Headform peak linear acceleration (PLA) and peak angular acceleration (PAA) were higher when tested with a medium helmet (tight fit, 99th%ile interface pressure) compared to a large helmet (looser fit, 39th%ile interface pressure); however, the sample size was small in some conditions (n=3) and the effect of hair was not tested. In another study, players wearing a helmet subjectively identified as a "poor fit" by an athletic trainier sustained greater severity and longer duration concussion symptoms than players wearing a properly fitting helmet [2], but 'poor' and 'proper fit' were not objectively defined and head kinematics were not quantified. Here, we sought to assess the combined effects of hair and football helmet fit on peak headform kinematics and hypothesised that hair and loose helmet fit generate lower peak headform kinematics compared to no hair and a tight helmet fit.

II. METHODS

A mandibular loading-sensing headform (MLSH), which is based on a 50th%ile Hybrid III headform fit with an articulating mandible and dentition [3], was mounted to a sliding table via a Hybrid III neck (total mass 23.5 kg). The MLSH was covered with two layers of nylon and a large Riddell Revolution Speed helmet (Riddell, Rosemont, IL; mass 2.07 kg, including the Head Impact Telemetry System (HITS)) was fit onto the headform according to the manufacturer's instructions. Large cheek pads (32 mm thick) were used in the helmet and a custom-fit mouthguard (X2 Biosystems, Seattle, WA) was placed on the upper dentition of the MLSH. Data from the HITS and mouthguard are not analysed here. A linear impactor (Biokinetics and Associates Ltd., Ottawa, ON) delivered either a nominally centroidal impact to the left side (SD) of the helmet or an eccentric impact (EC) from the same direction posterior to the headform's centre of mass at 7.4 m/s (Fig. 1). The impactor (14 kg) was covered with a vinyl nitrile pad (36 mm thick, 127 mm diameter) and a plastic cap (127 mm radius) to simulate a helmet strike. Eight helmet samples were cycled through during testing.

Four conditions were tested eight to ten times each at the Southern Impact Research Center (SIRC, Rockville, TN): no hair, with hair (human hair wig, Eva & Co. Wigs, Vancouver, BC, Fig. 1), with the helmet tight, and with the helmet loose. In the tight condition, the inflatable liner pads were inflated to 14 kPa prior to each test (~80th%ile as reported by [1]), and the chinstraps fastened to lower/upper buckles on the helmet were 320/440 mm long, respectively. In the loose condition, the inflatable liner pads were vented to atmosphere and both chinstrap components were elongated by 20 mm at each buckle. The cheek pads remained at atmospheric pressure for all conditions.

A 3-2-2-2 array of linear accelerometers (Endevco 7264B-2000 g, San Juan Capistrano, CA) were installed in the MLSH in a compact cluster (r_x = r_y = 34 mm, R_z = 27 mm). PLA, PAA and the angular acceleration pulse duration (Δt) related to the peak angular velocity change ($\Delta\omega$) were computed. The effect of hair and helmet fit on these four variables was assessed with a general linear model and post-hoc Tukey's tests were performed on the interactions. All tests were performed using Minitab (State College, PA) and a significance level of $\alpha = 0.5$.

III. INITIAL FINDINGS

The impactor speed was 7.39 $\pm$0.06 m/s and did not vary between conditions. Hair and a loose helmet reduced PLA and PAA at both impact locations and $\Delta\omega$ at the SD location (Table I). Neither factor affected $\Delta\omega$ at the EC location. Hair and a loose fit increased Δt at the SD and E locations, respectively. The hair × fit interaction

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was significant for PAA and Δt at SD only. Significant differences in pair-wise comparisons are shown in Table I.

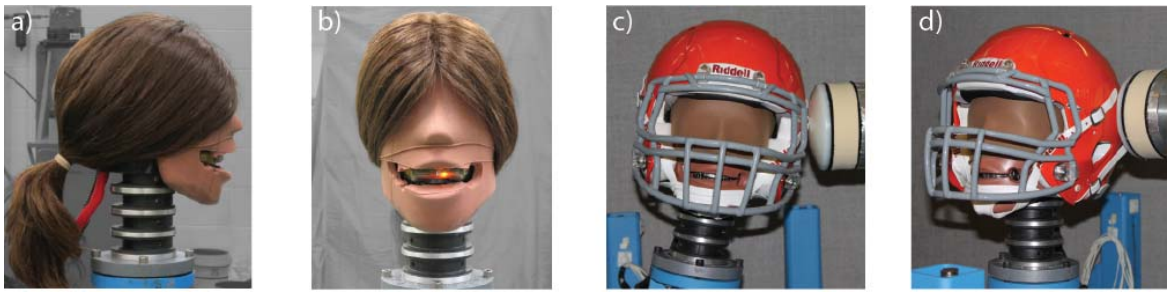

Fig 1. MLSH with the human-hair wig: a) side-view, b) front-view. Two impact locations: c) side, d) eccentric.

Table I

Mean (SD) for PLA, PAA, Δt, and Δω for all four test conditions. Significant factors are given in black text below each table. Post-hoc differences between cells re separated by dark lines (adjacent) or opposing triangles (diagonal).

PLA (g)

		No Hair	Hair
Side	Tight	76.6 (2.2)	70.5 (5.4)
	Loose	71.6 (2.3)	68.7 (2.6)
Eccentric	Tight	58.5 (1.7)	57.0 (1.8)
	Loose	56.6 (1.3)	54.2 (1.6)

Hair Fit H×F

PAA (rad/s²)

		No Hair	Hair
Side	Tight	4660 (96)	4399 (226)
	Loose	4329 (160)	4412 (175)
Eccentric	Tight	5451 (149)	5209 (183)
	Loose	5233 (163)	4929 (175)

Hair Fit H×F

Δt (ms)

		No Hair	Hair
Side	Tight	13.7 (0.4)	15.4 (1.8)
	Loose	14.2 (0.4)	14.2 (0.3)
Eccentric	Tight	13.0 (0.4)	13.3 (0.5)
	Loose	13.3 (0.3)	13.5 (0.4)

Hair Fit H×F

Δω (rad/s)

		No Hair	Hair
Side	Tight	37.1 (0.9)	35.1 (1.7)
	Loose	35.3 (0.6)	34.0 (0.9)
Eccentric	Tight	37.7 (1.1)	37.8 (0.5)
	Loose	38.0 (0.4)	37.5 (0.6)

Hair Fit H×F

IV. DISCUSSION

This study examined the effect of hair and helmet fit on headform kinematics during side and eccentric impact locations at ~7.4 m/s. Compared to the no hair and tight fit condition, the presence of hair and a loose helmet condition resulted in ~10% lower PLA, PAA and Δω at the SD location and similarly lower PLA and PAA at the EC location. These findings indicate that hair at the head-helmet interface and/or a loose helmet attenuate a head impact, possibly by allowing more movement of the helmet relative to the headform during the impact. Interestingly, the pattern of pairwise differences in these variables suggests that the two effects are not superimposed, a finding that further suggests there is a limit to the benefit of looser coupling between the head and helmet. Neither hair nor helmet fit was a significant factor for Δω at the EC location. This unexpected outcome may be due to the lower PAA values for the hair/loose conditions being offset by the slightly (though not significantly) longer Δt, resulting in an aggregate effect, i.e. Δω that was not different. Further work is needed to assess this and other potential explanations.

The kinematic patterns we observed are consistent with those reported by Jadischke *et al.* [1], but they do not appear to support the more severe and longer duration concussion symptoms reported for players with poorly fitting helmets [2], possibly because our loose helmet conditions did not reproduce their poorly fitting helmets. Further work may be needed with even looser helmets to assess this phenomenon. Our work was limited to two hair conditions, two fit conditions, two impact locations and one impact speed. Future work will need to expand these conditions, and also analyse the wearable sensor data to determine if they can detect the

hair and fit effects observed here. Nevertheless, the current work shows a small but significant attenuation of peak headform kinematics with hair and a slightly loose helmet.

V. ACKNOWLEDGEMENTS

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VI. REFERENCES

[1] Jadischke, *J Biomech,* 2013. [2] Greenhill, *Sports Health*, 2016. [3] Siegmund, G. P., ABME, 2014.